Paper presented at the Nov. 1998 ASME IMECE conference in Anaheim, CA
Symposium on Microscale Mechanics of Materials and Structures

ADHESION, ADHESION HYSTERESIS AND FRICTION IN MEMS UNDER CONTROLLED HUMIDITY AMBIENTS†

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EXTENDED ABSTRACT

In surface micromachining, compliant structures and high surface to volume ratios render surface properties such as adhesion and friction critical parameters in system reliability. The adhesion and friction of polycrystalline silicon (polysilicon) MEMS structures depends strongly on the ambient to which they are subjected. This dependence is reduced, but not eliminated, when molecular coatings are applied to their surfaces. From measured adhesion energy (Γ, J/m^2) for uncoated beams, we demonstrate that capillary condensation produces an exponential dependence of adhesion on relative humidity (RH). For coated beams, we demonstrate that after substantial exposure to high RH ambients, adhesion begins to vary along the length of the beam. This implies a localized breakdown mechanism of the molecular coating. Finally, we present data on a new structure to measure friction in MEMS. With this structure, we can infer slip on a nanometer length scale.

We exposed uncoated polysilicon beams with a thin oxide surface to various RH levels, and observed that the length in contact with the substrate increased with RH, as seen Fig. 1 [1]. Adhesion can be determined on each of these beams. The data in Fig. 2 indicates that adhesion increases exponentially with RH from 30% to 95%, with values from 1 mJ/m^2 to 50 mJ/m^2. Using the Kelvin equation, we show that the data should be independent of RH if a smooth interface is considered (Calc #1 in Fig. 2). By modeling a rough interface consistent with atomic force microscopy (AFM) data, the exponential trend is satisfactorily explained (Calc #2 in Fig. 2).

If initially non-contacting structures come into contact while in operation, interfacial forces may cause them to adhere. If surfaces change due to exposure, these forces may increase over time, giving rise to the phenomenon of adhesion hysteresis. We demonstrate the mechanics and measurement of adhesion hysteresis in surface micromachined polycrystalline silicon beams subject to dry and wet ambients [2]. Beams were treated with hydrophobic molecular coatings such as octadecyltrichlorosilane (ODTS, $C_{18}H_{37}SiCl_3$) or perfluorodecyltrichorosiliane (FDTS, $C_{10}H_4F_{17}SiCl_3$). Results indicate that apparent adhesion values increase after an incubation period at RH approaching 90% and above. We measure apparent adhesion energies for crack healing and repropagation on the structure schematically represented in Fig. 3, where *s* is considered to be the crack length in a fracture mechanics approach. Higher adhesion values are observed only upon repropagation, as seen in Fig. 4. Hence the forces involved are very short range. Furthermore, upon repropagation, we observe apparent non-uniformities in the adhesion energy, suggesting that the high humidity environment induces localized breakdown of the molecular film coating.

We have designed and performed initial testing of a new test structure for friction measurement in MEMS [3]. The device consists of a cantilevered forked beam and a friction pad attached via a hinge, as represented in Fig. 5. Benefits include friction measurement over large normal pressure and velocity ranges, while only a small area is occupied. The placement of the hinge is crucial to obtaining a well-known and constant pressure distribution. Static deflections on the device were both measured and modeled numerically. Preliminary results indicate that friction pad slip is sensitive to friction pad normal force. This was inferred from interferograms, as seen in Fig. 6.

We expect the results from these measurements to increase our fundamental understanding of surface forces in MEMS devices. This ultimately will lead to improved model-based designs, higher performance and greater reliability.

REFERENCES

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[†] Sandia National Laboratories is a multiprogram laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

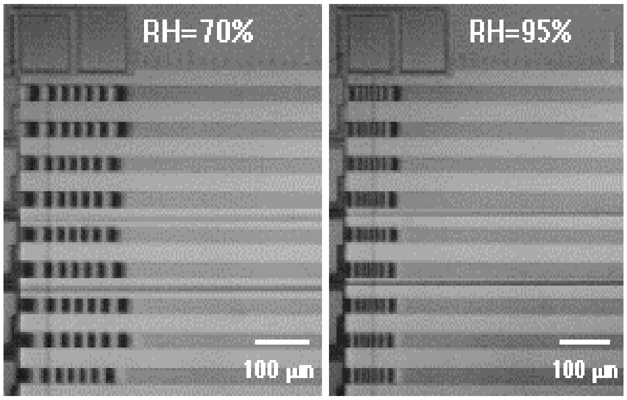

Fig. 1 Interferograms of adhered beams versus relative humidity (RH).

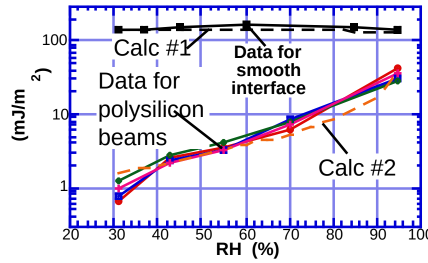

Fig. 2 Adhesion energy vs. RH for uncoated beams.

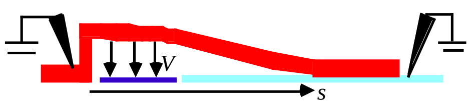

Fig. 3 Experimental test structure to determine adhesion hysteresis

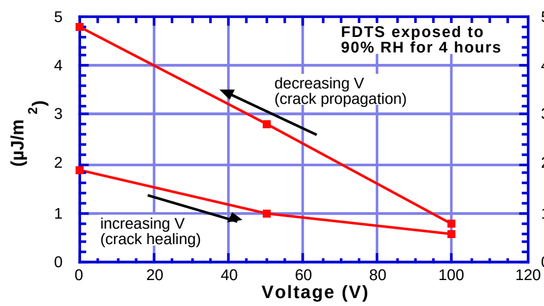

Fig. 4 Adhesion energy Γ for healing and propagating cracks (FDTS coating).

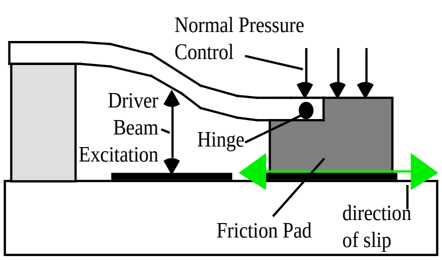

Fig. 5 Schematic of friction test structure

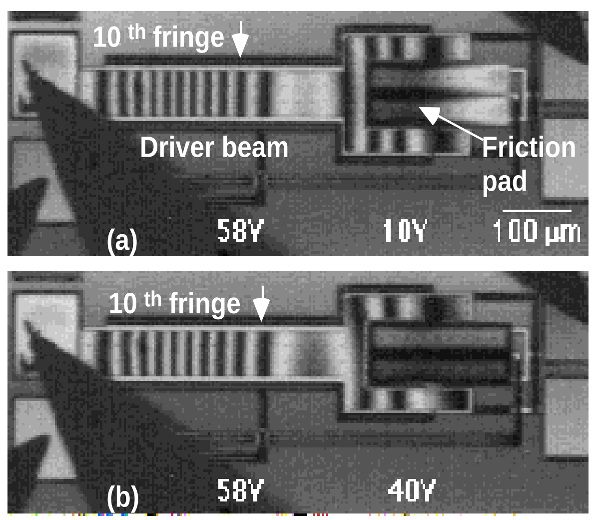

Fig. 6 Demonstration illustrating effect of friction force on driver beam deformations